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Research Paper

Soil moisture estimation in Ferlo region (Senegal) using radar (ENVISAT/ASAR) and optical (SPOT/VEGETATION) data

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A B S T R A C T

The sensitivity of the radar signal to the seasonal dynamics in the Sahel region is a considerable asset for monitoring surface parameters including soil moisture. Given the sensitivity of the radar signal to vegetation mass production, roughness and soil moisture, the main problem has been to estimate the contribution of these three parameters to the signal. This study aims to circumvent this problem by combining radar with optical data. The DMP (Dry Mater Product) extracted from SPOT data allowed to estimate vegetation mass production. Surface roughness was estimated from radar data during the dry season. Because during the dry season, radar signal is only conditioned by soil roughness in this region a Radiative Transfer Model (RTM) was used: it consists in a microwave scattering model of layered vegetation based on the first-order solution of the radiative transfer equation and it accounts for multiple scattering within the canopy, surface roughness of the soil, and the interaction between canopy surface and soil.

This model was designed to account for the branch size distribution, leaf orientation distribution, and branch orientation distribution for each size. In this study, the RTM has been calibrated with ESCAT (European Radar Satellite Scatterometer) data, and has been used in order to estimate soil moisture.

The results obtained have allowed to track the spatial and temporal dynamics of soil moisture on the one hand, and on the other hand the influence of geology and morphopedology on the spatial dynamics of the soil moisture variability. These results are promising despite the fact that the inversed RTM often faces difficulties to interpret the signal for saturated soils, giving an aberrant value of soil moisture more often than not.

1. Introduction

Estimating and monitoring the spatial and temporal evolution of soil moisture is of paramount importance in many areas. They allow among other things, better monitoring of crops and agricultural yields. Radar remote sensing offers strong potential for applications, due to its sensitivity to the dynamics of continental surfaces. Indeed, some studies have underlined the strong seasonal dependence of the radar signal in semi-arid zones, especially in the Sahel, which makes it possible to discriminate the alternative dry and wet seasons (Baup et al., 2007; Dubois et al., 1995; Faye

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et al., 2011; Frison and Mougin, 1996a,b; Frison et al., 1998; Jarlan et al., 2003; Le Toan et al., 1981; Magagi and Kerr, 1997; Naeimi et al., 2009; Pellarin et al., 2006; Wagner et al., 1999, 2000; Woodhouse and Hoekman, 2000; Zine et al., 2005; Zribi and Dechambre, 2002). In the Sahel region, the radar signal is sensitive to land surface parameters: vegetation mass production, roughness and soil moisture (Ulaby et al., 1978; Bernard et al., 1981; Bradley and Ulaby 1981; Bruckler et al., 1988; Dobson and Ulaby 1986; Naeimi et al., 2009). Globally radar sensors have demonstrated their potential for the effective measurement and monitoring of soil surface characteristics (Baghdadi et al., 2008; Rahman et al., 2008; Thoma et al., 2008; Anguela et al., 2010; Pandey and Pandey 2010; Aubert et al., 2011; Zribi et al., 2011; Molin and Faulin, 2013; Castaldi et al., 2014; Gorrab et al., 2015).

In fact the temporal evolution of the radar signal is strongly correlated with the increase in soil moisture and the development of vegetation (Faye et al., 2011; Zine et al., 2005; Zribi and Dechambre, 2002). In the past two decades some studies have aimed to estimate soil moisture from radar remote sensing data, (Baghdadi et al., 2012; Castaldi et al., 2014; Wagner et al., 2000) and data acquired with Synthetic Aperture Radar (SAR) yielded fairly consistent results (Zribi and Dechambre, 2002; Zribi et al., 2014).

The purpose of this work was to estimate soil moisture in semi-arid areas of Senegal by using the ENVISAT ASAR (Advanced Synthetic Aperture Radar) data and a Radiative Transfer Model (RTM), which is a backscattering model based on the first-order solution of the radiative transfer equation (Karam et al., 1992). However, considering the dependence of the radar signal on the three surface parameters (soil moisture, surface roughness and biomass) the main difficulty encountered was how to determine the singular contribution of each parameter to the radar response.

For this reason, we calculated soil roughness from dry season radar data and vegetation mass from the Dry Mater Productivity (DMP) product derived from the SPOT VEGETATION-2 optical sensor data on SPOT-5 satellite (Bégué, 2002; Kumar and Monteith, 1981; Varlet-Grancher et al., 1982; ftp. www.vito-eodata.be/).

2. Data and methods

2.1. Study areas

The study area was in Senegal, covering the Sylvo-Pastoral zone of the Ferlo region and the northern groundnut basin. It expands to the coastal fringe (Fig. 1). The western part of the study area, which covers a large part of the coastal fringe, is characterized by a shallow aquifer, fairly extensive tree/shrub vegetation over a sandy soil, while the eastern part lays in the Ferlo region (Fig. 1) and is characterized by a water table that reaches up to 100 m deep. The annual rainfall is estimated to be between 200 and 500 mm, with a high inter-annual variability.

The western area and a large part of half of the northern area are dominated by a shrub steppe with sparse trees. Rainfed agriculture occupies the western and southern part of the study area, whereas irrigated crops dominate in the northwest, along with some marshy meadows. The southeast with a shrub savannah is a pasture zone.

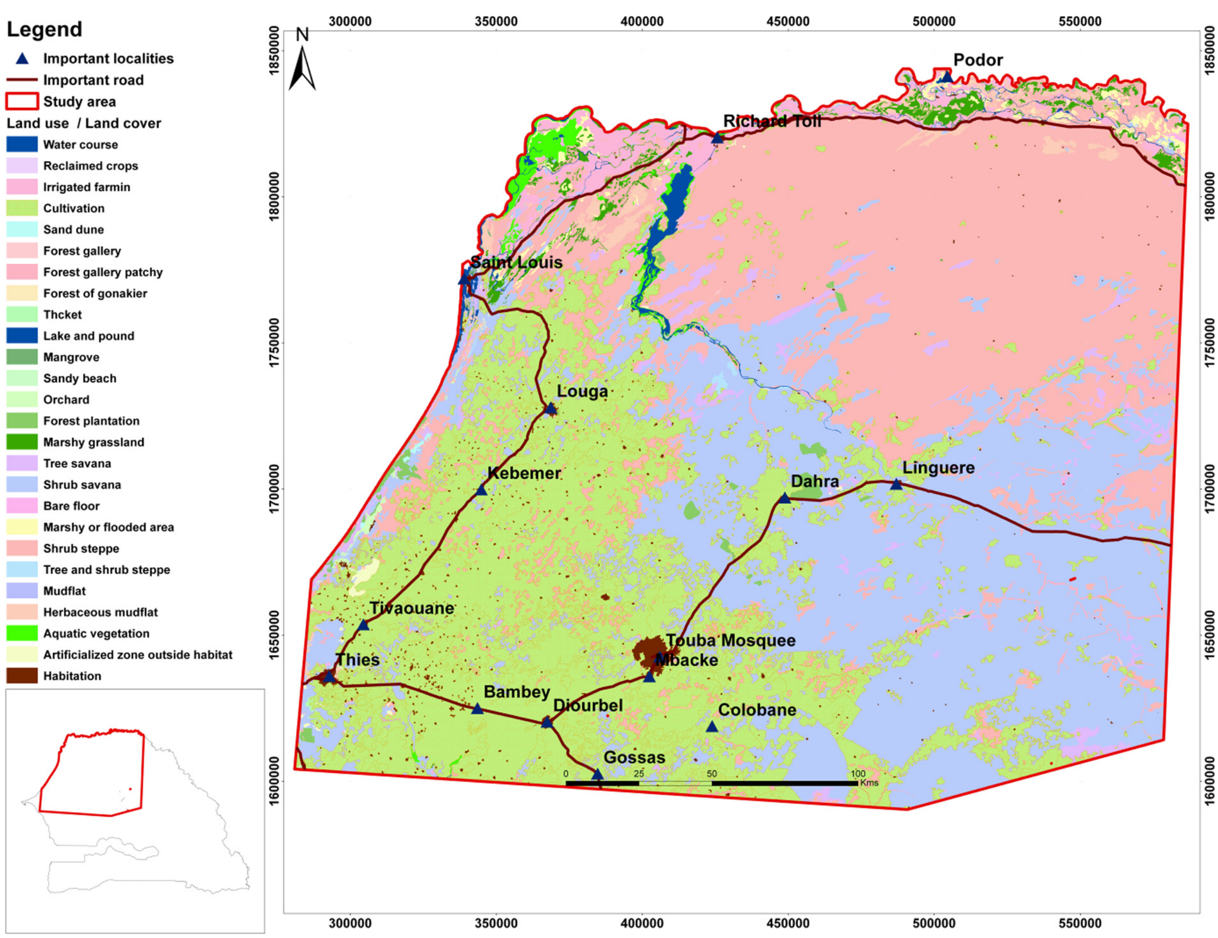

Fig. 1. Land use, land cover of the study area (PNAT, 1986).